The American College of Radiology (ACR) Phantom and Performance Evaluation for CT Accreditation

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Presentation Overview

- ACR Accreditation Program and Phantom
- Accreditation Requirements
  - Table I and SMPTE Pattern
  - Alignment
  - Module 1
  - Module 2
  - Module 3
  - Module 4
- CTDI Data Requirements
  - CTDI Data sheet

ACR CT Accreditation

- Started in 2002
- Performance evaluation based on the MTFs current clinical protocols
- Requirements
  - Approximately 20 images (Film page)
  - CT parameter table (Table 1)
  - Data sheets (Data taken from each module)
  - 3 Excel Worksheets (CTDI data)

Film Page:

Box 1 – SMPTE	Box 2	Box 3
Box 4	Box 5	Box 6
Box 7	Box 8	Box 9
Box 10	Box 11	Box 12

ACR CT Accreditation Phantom

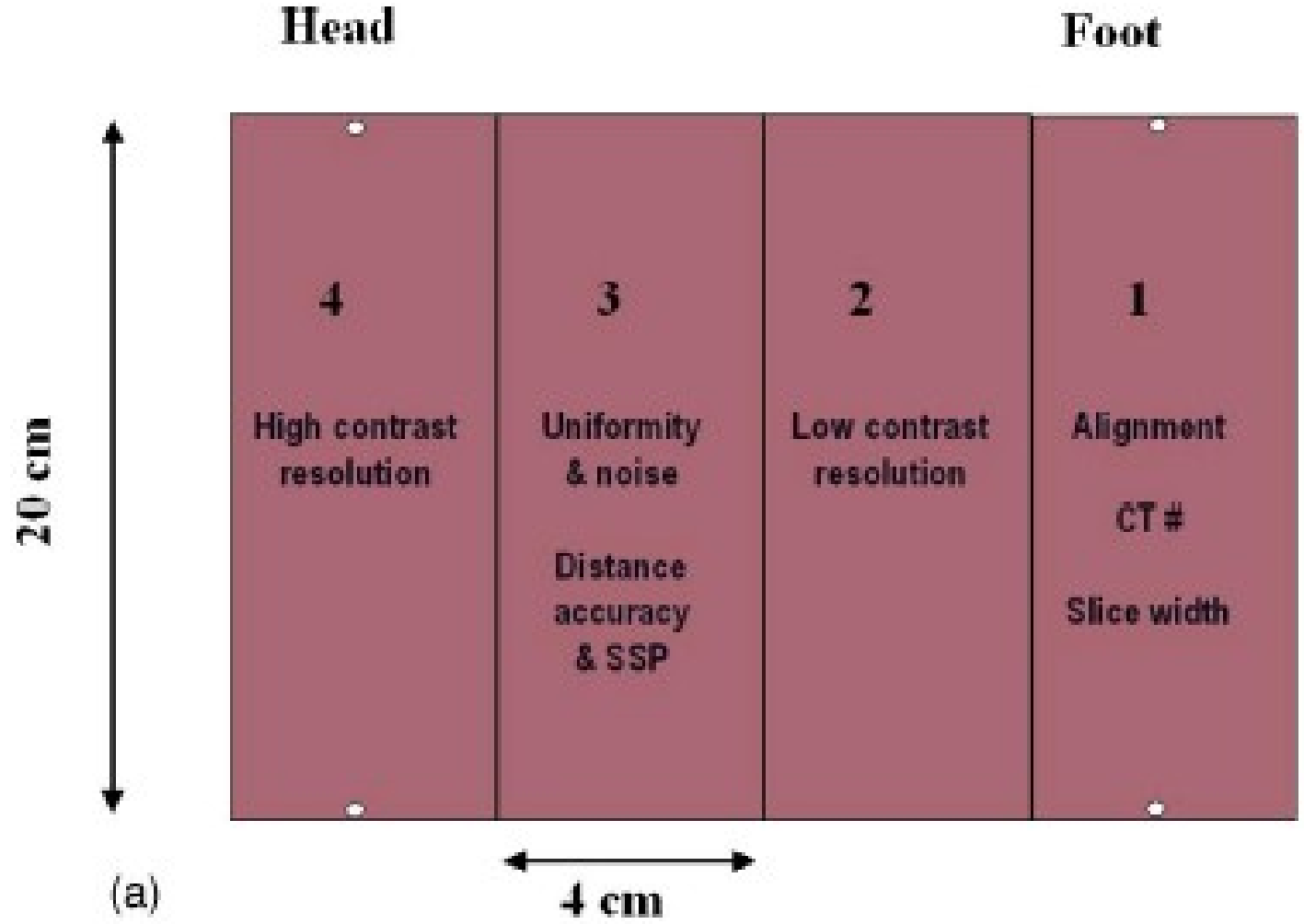
- Gammex-RMI Model 464
- Constructed primarily of a water equivalent material
- Solid phantom containing 4 modules
  - 4 cm wide x 20 cm diameter
  - External alignment markings (centering phantom)
  - Head, Foot, and Top markings
  - Optional phantom support base

ACR CT Accreditation Phantom

- Designed to examine a broad range of image quality parameters
  - Position accuracy
  - CT # accuracy
  - Slice width
  - Low contrast resolution
  - High contrast (spatial) resolution
  - CT # uniformity
  - Image noise

ACR CT Accreditation Phantom

McCollough *et al.*: Phantom portion of the ACR CT accreditation program



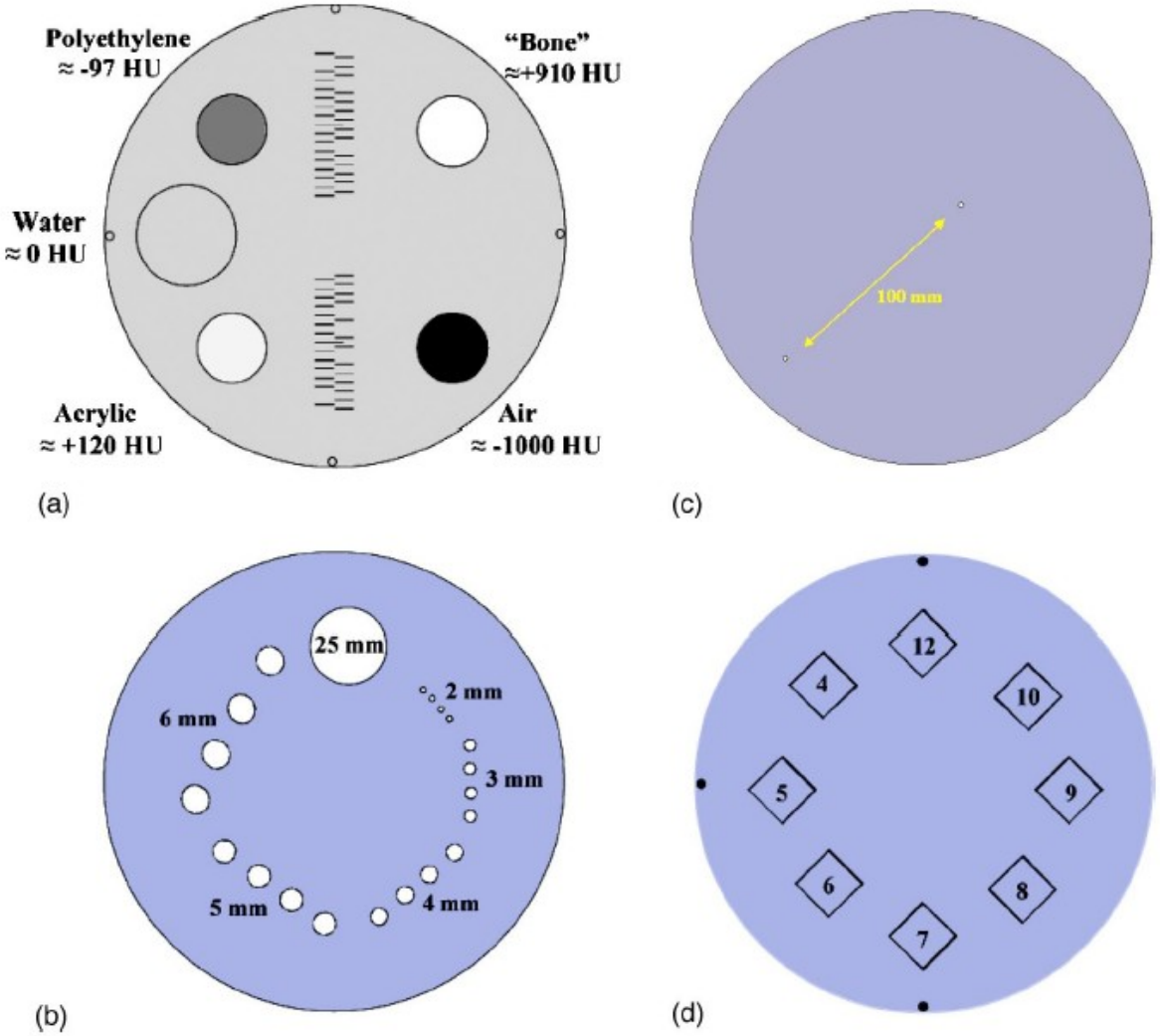
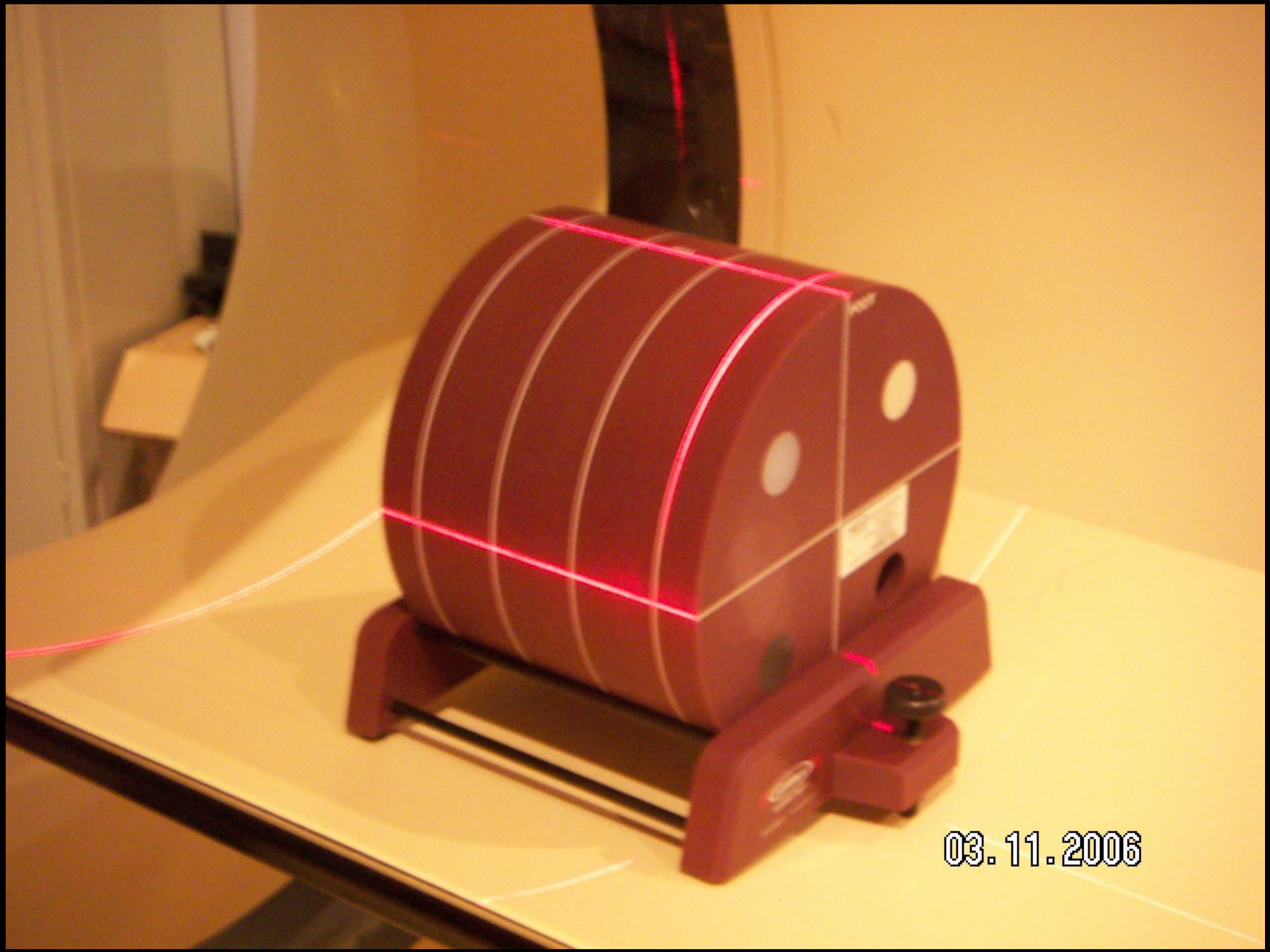


FIG. 13. (a) Cross-sectional diagram of module 1, which contains four cylindrical rods to assess the CT number of different materials, four BBs to confirm accurate positioning, and two inclined ramps consisting of discrete wires that are spaced in 0.5 mm increments along the z axis. (b) Cross-sectional diagram of the low-contrast resolution test objects contained in module 2. Each cylinder is comprised of the material having a nominal CT number difference from the background material equal to 6 HU. (c) Cross-sectional diagram used to assess image uniformity in module 3. The two 0.28 mm beads are used for optional assessment of distance accuracy or section-sensitivity profile. (d) Cross-sectional diagram of the high contrast (spatial) resolution test objects contained in module 4. The numerical values shown correspond to the spatial frequency of the respective bar pattern, in lp/cm.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ACR CT Accreditation Requirements

Table I

- Critical element of submission process that is representative of sites routine clinical scans
- Consistent with image data
- Protocols
  - Head
  - HRC
  - Adult Abdomen
  - Pediatric Abdomen (If applicable)

TABLE I. Typical image acquisition technical parameters.

	Adult head (cerebrum portion)	High resolution chest	Adult abdomen	Pediatric abdomen (5 y.o.)
kVp	120	140	120	120
mA	170	120	240	110
Time per rotation (s)	2	0.8	0.8	0.8
Scan FOV (cm or name)[a]	Head (25 cm)	Large (50 cm)	Large (50 cm)	Large (50 cm)
Display FOV (cm)[a]	25	38	38	30
Reconstruction algorithm	Std	Bone	Std	Std
Axial (*A*) or helical (*H*)	*A*	*A*	*H*	*H*
Z-axis collimation (*T*, in mm)[b]	2.5	1.25	3.75	2.5
No. of data channels *used*[b] (*N*)	4	1	4	4
A: Table increment (mm) or *H*: Table speed (mm/rot) (*I*)[b]	10	10	11.25	15
Pitch[c]	...	...	0.75 (HQ)	1.5 (HS)
Reconstructed scan width (mm)	5	1.25	5	5
Reconstructed scan interval (mm)	5	10	5	5
Dose reduction technique(s)[d]	...	...	mA modulation	mA modulation

[a]FOV=field of view

[b]*z-axis collimation* (*T*)=the width of the tomographic section along the *z*-axis imaged by one data channel. In multidetector row (multislice) CT scanners, several detector elements may be grouped together to form one data channel.
Number of data channels (*N*)=the number of tomographic sections imaged in a single axial scan.
Maximum number of data channels (N_{max})=the maximum number of tomographic sections for a single axial scan.
Increment (*I*)=the table increment per axial scan or the table increment per rotation of the x-ray tube in a helical scan.

[c]Applied to helical scanning. Compute pitch according to the IEC definition: Pitch=table speed (mm/rotation)/$N \cdot T$ (mm)=$I/N \cdot T$. For some scanners, this computed value might differ from the value given by the manufacturer.

[d]If selectable, list selection, otherwise leave blank. Example: mA modulation based on patient attenuation.

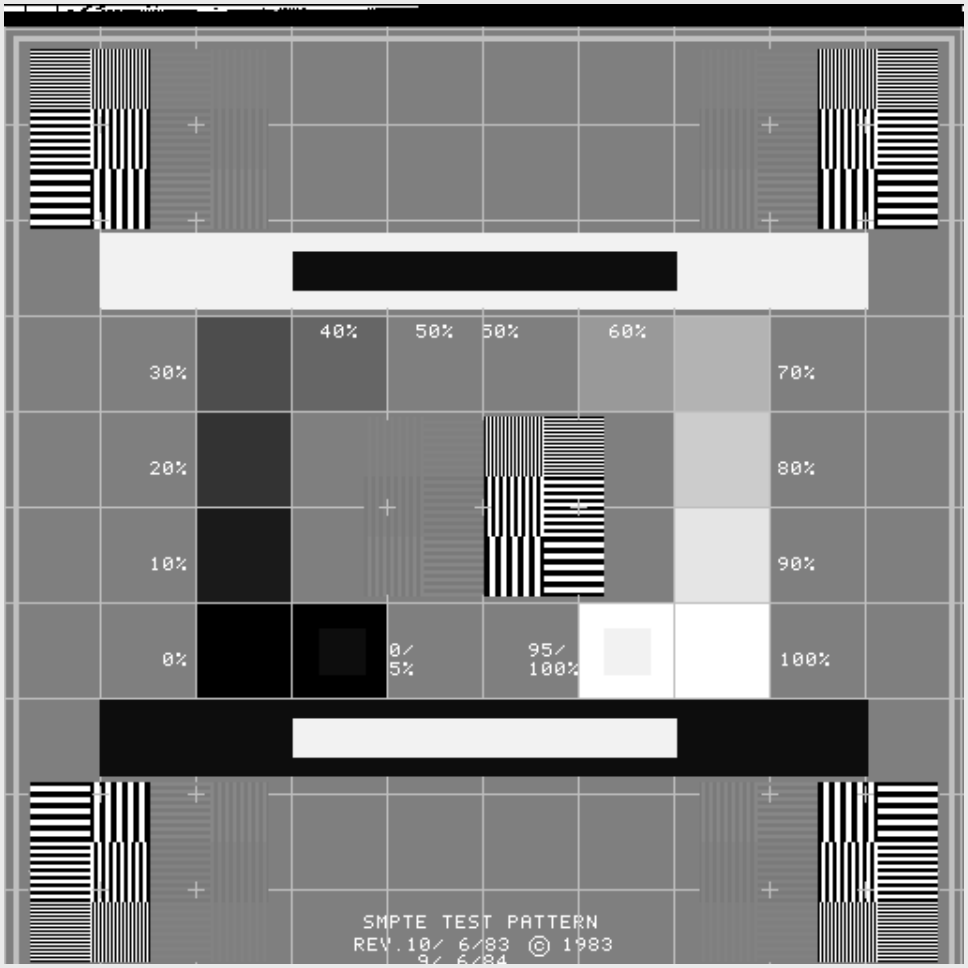
Common Table I errors

SMPTE Test Pattern

- SMPTE test pattern (required)
  - Demonstrates the quality of submitted hard copy films
- Failure to submit SMPTE results in automatic failure
- Alternate patterns are accepted, but not recommended

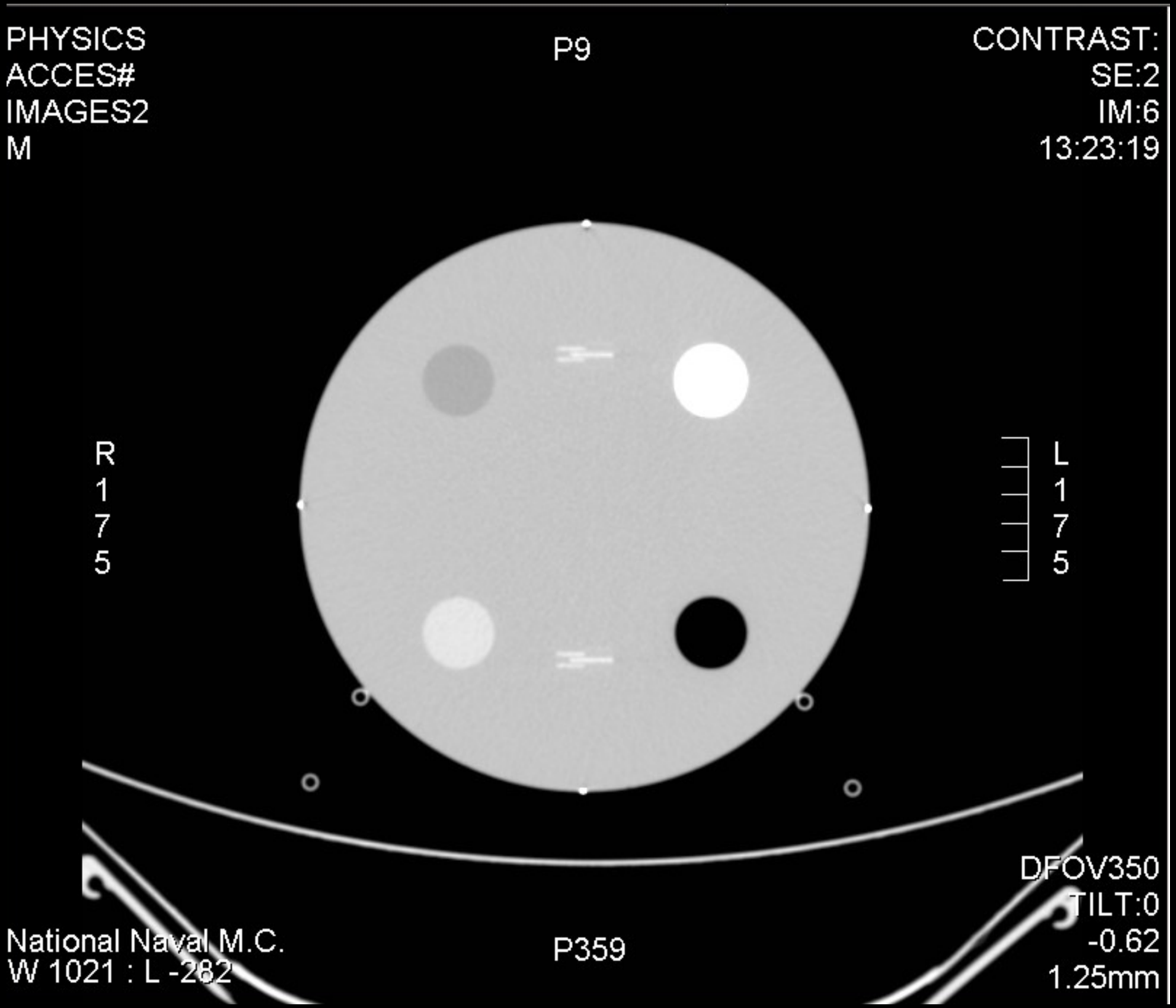
Essential Criteria

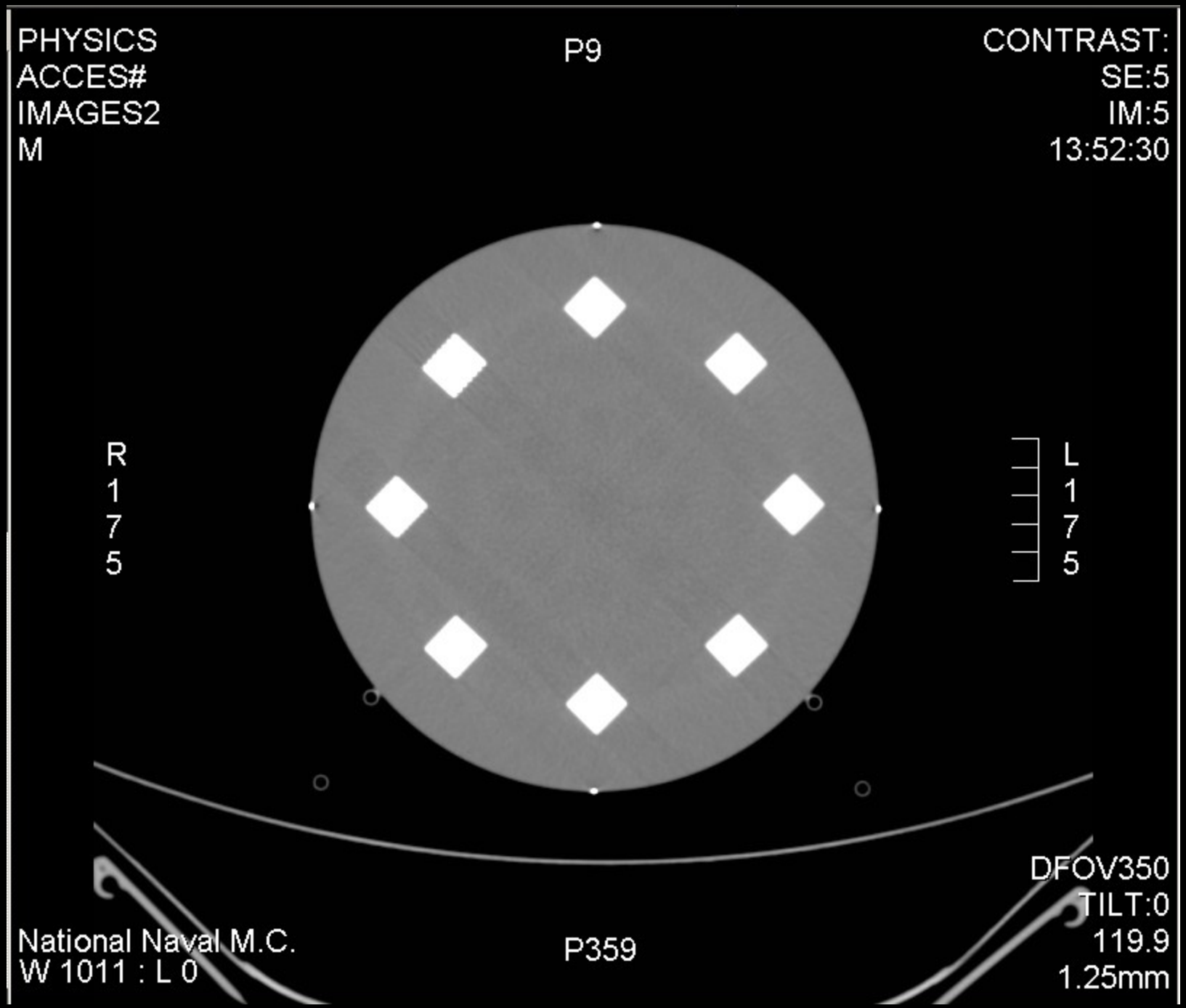
- First box of each film sheet
- 95% visible
- 5% visible
- Whites and blacks must not be saturated
- No aliasing of bar patterns



Alignment

- Modules 1 and 4
- HRC protocol (< 2 mm scan width)
  - Scan phantom at S0 and S120
  - Scan 1mm superior and inferior to each mark
  - WW = 1000 and WL = 0
- Proper alignment
  - 4 BB’s seen in one image with similar appearance in both module 1 and 4
  - The longest wire centrally located (+/- 1 wire) on both top and bottom ramps
  - Must pass alignment test to proceed


PHYSICS
ACCES#
IMAGES2
M
P9
CONTRAST:
SE:2
IM:6
13:23:19
R
1
7
5
L
1
7
5
DFOV350
TILT:0
-0.62
1.25mm
National Naval M.C.
W 1021 : L -282
P359


PHYSICS
ACCES#
IMAGES2
M
P9
CONTRAST:
SE:5
IM:5
13:52:30
R
1
7
5
L
1
7
5
National Naval M.C.
W 1011 : L 0
P359
DFOV350
TILT:0
119.9
1.25mm

CT Number Calibration

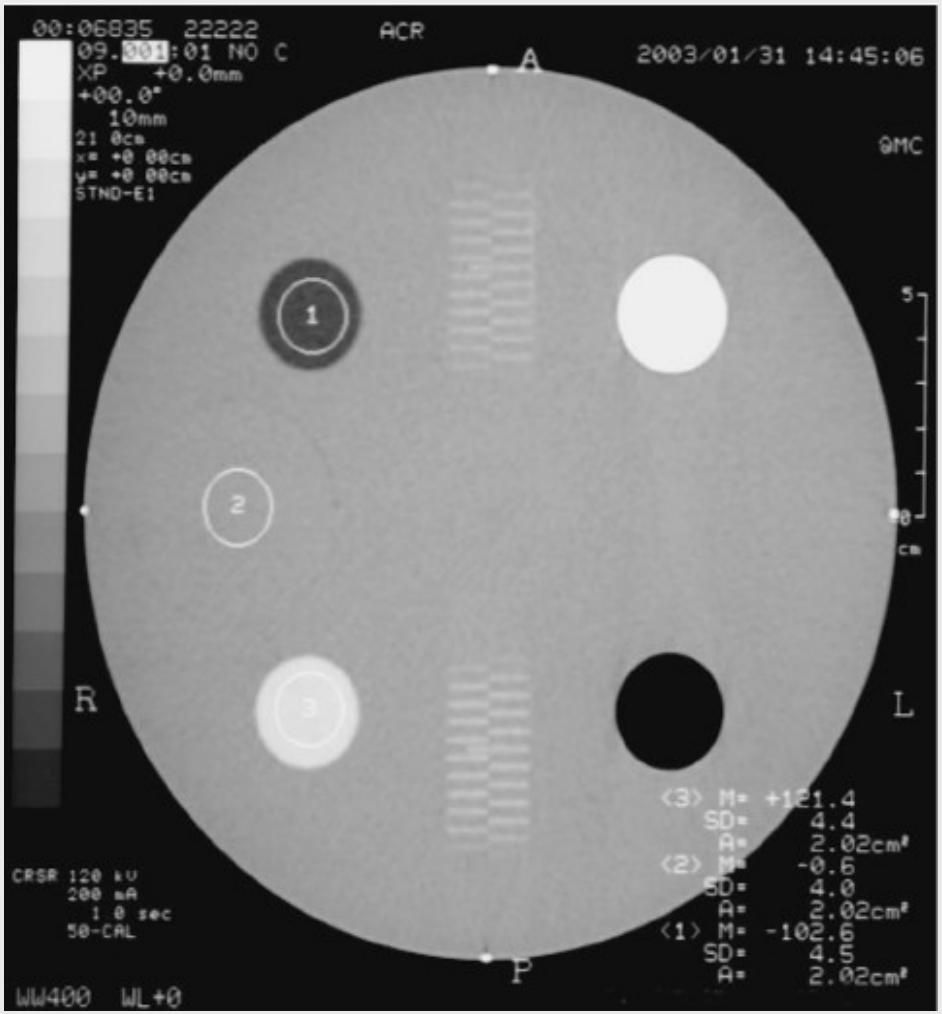
- Initial alignment at Module 1(foot)
  - S0 or 0 position
- Embedded test objects in Module 1
  - Low density polyethylene (LDPE)
  - Acrylic
  - Bone equivalent
  - Air
  - Solid Water

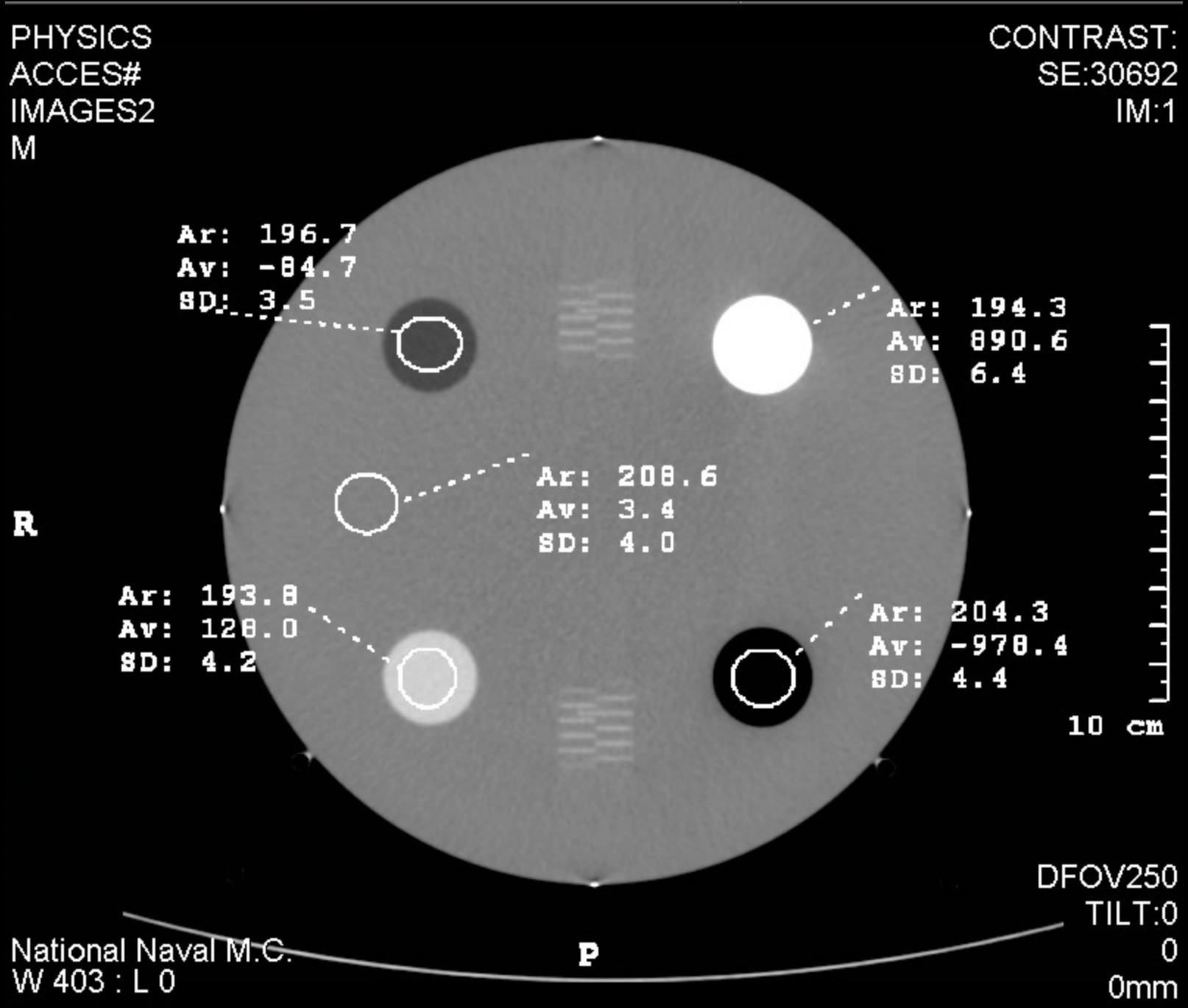
CT Number Calibration

- Scan ACR phantom at S0
  - Adult abdomen protocol
  - Scan in Axial mode
  - Multislice scanners
    - Center scan so that one image is centered at S0
- DFOV 21 - 25 cm
- Circular ROIs ≈ 200 mm^2 over each peg

CT Number Calibration

- WW = 400, WL = 0
- Polyethylene
  - **-107 to -87 HU**
- Water
  - **-7 to +7 HU (+/-5 HU)**
- Acrylic
  - **+110 to +130 HU**
- Bone
  - **+850 to +970 HU**
- Air
  - **-1005 to -970**




PHYSICS
ACCES#
IMAGES2
M
CONTRAST:
SE:30692
IM:1
Ar: 196.7
Av: -84.7
SD: 3.5
Ar: 194.3
Av: 890.6
SD: 6.4
Ar: 208.6
Av: 3.4
SD: 4.0
R
Ar: 193.8
Av: 128.0
SD: 4.2
Ar: 204.3
Av: -978.4
SD: 4.4
10 cm
DFOV250
TILT:0
0
0mm
National Naval M.C.
W 403 : L 0
P

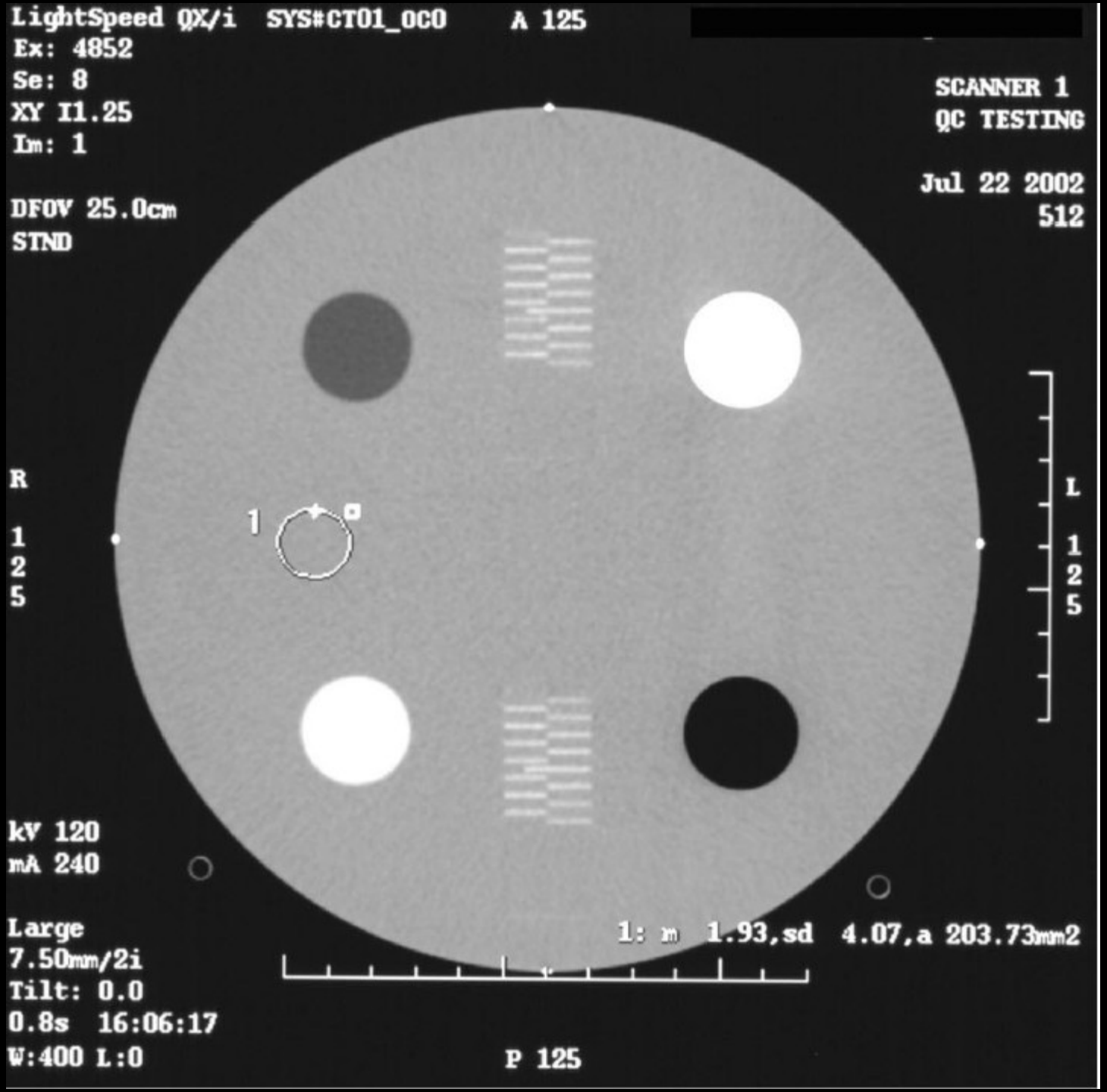
Slice Thickness

- Adult abdomen protocol (axial scan)
  - HRC slice thickness and ~3 mm, 5 mm, and 7 mm slice thickness at same window and level settings as before
- Mean CT of water (-7 to +7 HU)

- Verify slice thickness by counting pins
  - Count pins that appear to be 50% as bright as center pin and divide by 2
  - 0.5 mm apart
- Slice thickness must be within 1.5 mm of prescribed thickness

Water vs. kVp

- Adult abdomen scan (axial)
- Repeat previous scan at all kVp settings.
- Mean CT number of water should stay within the previous stated range (-7 to +7 HU)


LightSpeed QX/i SYS#CT01_0C0 A 125
Ex: 4852
Se: 8
XY I1.25
Im: 1
DFOV 25.0cm
STND
SCANNER 1
QC TESTING
Jul 22 2002
512
R
1
2
5
L
1
2
5
1
kV 120
mA 240
Large
7.50mm/2i
Tilt: 0.0
0.8s 16:06:17
W:400 L:0
1: m 1.93,sd 4.07,a 203.73mm2
P 125

Low Contrast Resolution

- Module 2
- Adult abdomen protocol
- DFOV 21- 25 cm

Low Contrast Resolution

- Axial Acquisition
  - Acquire 3 axial images at the following positions
    - S40 or 40 mm Superior
    - S80 or 80 mm Superior
    - S120 or 120 mm Superior
- Helical Acquisition
  - Start scan at S40
  - End scan at S120
  - Choose a 5 mm scan reconstruction interval to ensure that one image is reconstructed at the center of modules 2, 3, and 4
  - **Module 3 and 4 images will be analyzed in later section**

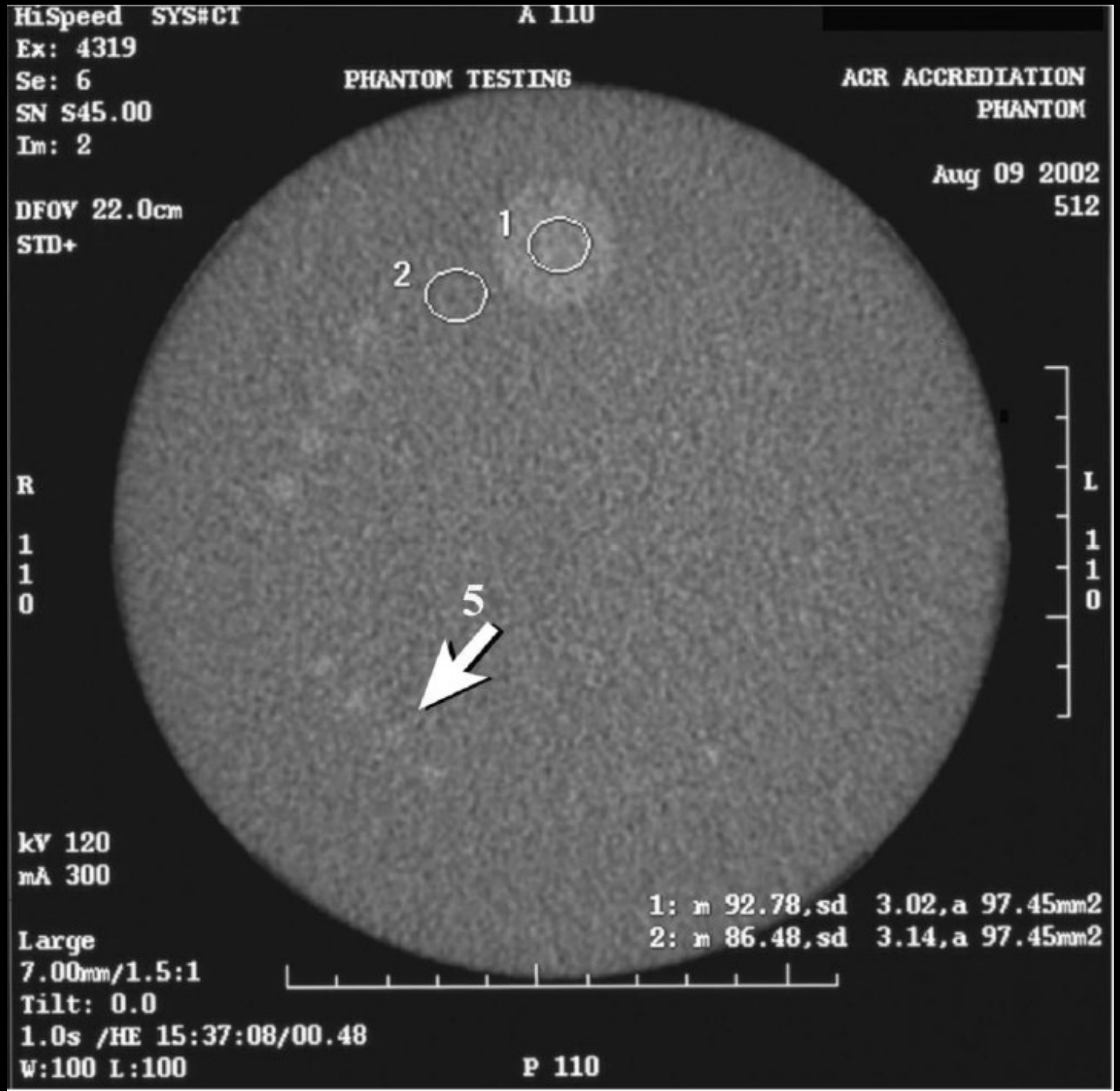
Low Contrast Resolution

- View image located at Module 2 center
  - WW = 100 WL = 100
- Determine smallest diameter of cylinder set in which ALL FOUR are clearly delineated
  - 2, 3, 4, 5, and 6 mm
- 6 mm cylinder set must be visualized

Low Contrast Resolution

- 100 mm^2 ROI
  - Inside 25 mm cylinder
  - Just outside the 25 mm cylinder
- Calculate CT number difference
  - ≈ 6 HU difference

- Repeat module 2 (low contrast) evaluation using the routine head protocol


HiSpeed SYS#CT
A 110
Ex: 4319
Se: 6
SN S45.00
Im: 2
PHANTOM TESTING
ACR ACCREDIATION
PHANTOM
Aug 09 2002
512
DFOV 22.0cm
STD+
1
2
R
1
1
0
5
L
1
1
0
kV 120
mA 300
1: m 92.78,sd 3.02,a 97.45mm2
2: m 86.48,sd 3.14,a 97.45mm2
Large
7.00mm/1.5:1
Tilt: 0.0
1.0s /HE 15:37:08/00.48
W:100 L:100
P 110

Uniformity, Noise, and In Plane Distance

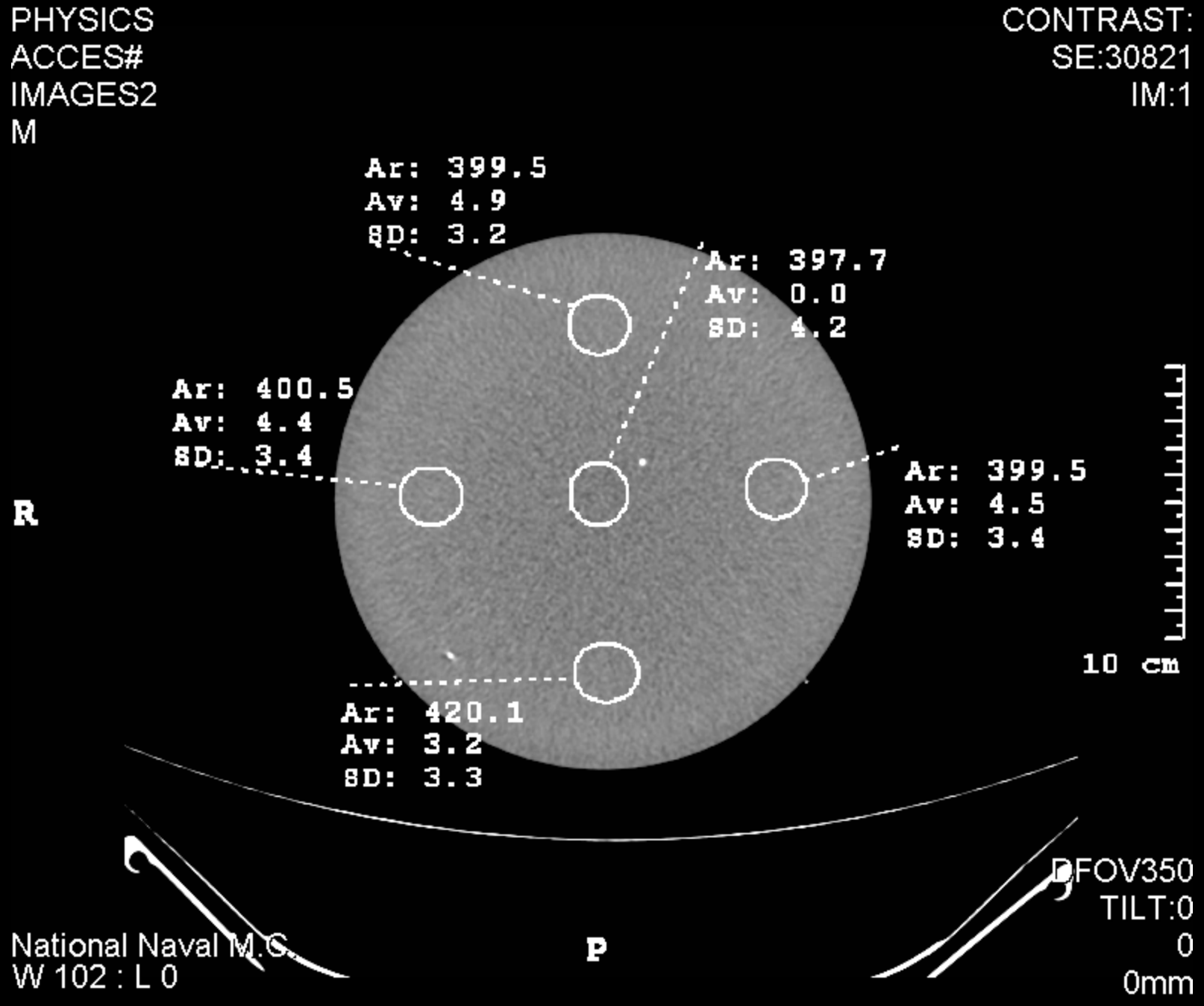
- Module 3
- View previously acquired Adult abdomen images
- WW = 100 WL = 0
- 400 mm^2 ROIs at center and four edge positions (12, 3, 6, and 9 o’clock)
  - One ROI diameter from the edge

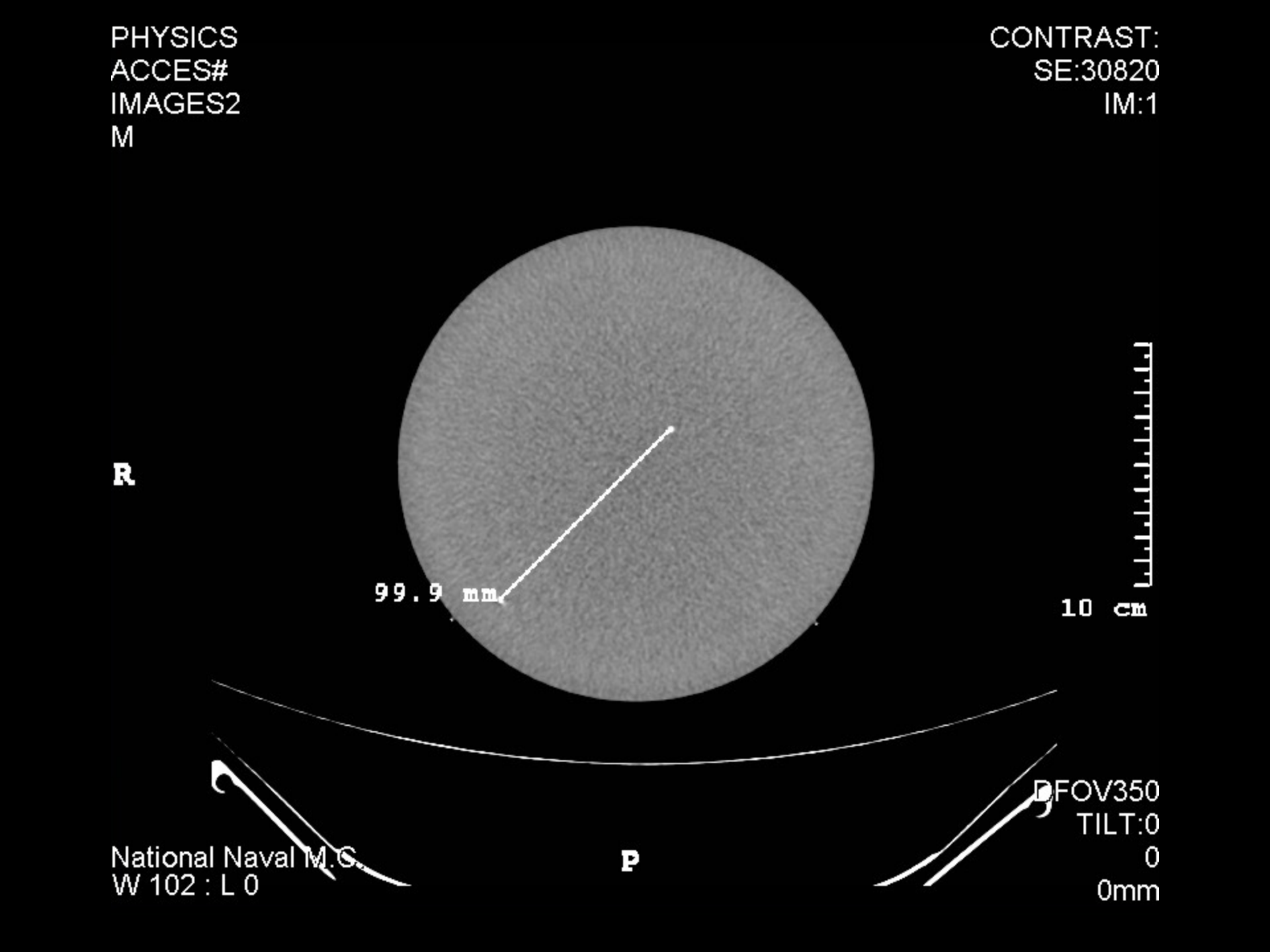
Uniformity, Noise, and In Plane Distance

- Record Mean CT numbers from all 5 ROIs
- Record Center ROI standard deviation
- Calculate the Uniformity value
  - ABS(Center Mean CT – Edge Mean CT)
  - Difference should be < 5HU for all four edge ROIs
  - Center Mean CT number should be (-7 to +7)

Uniformity, Noise, and In Plane Distance

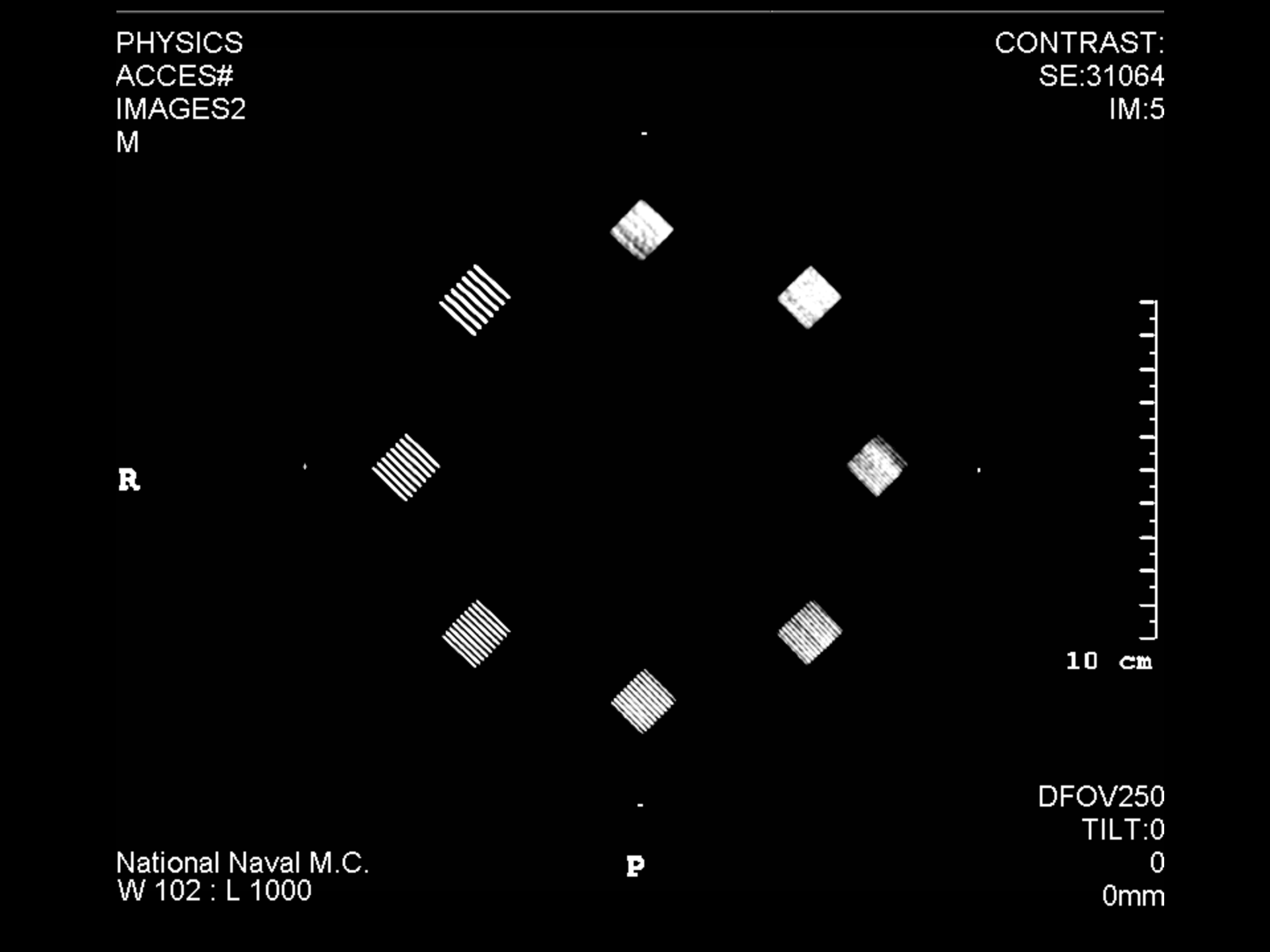
- Examine the image for artifacts such as rings or streaks
- Record the presences and appearance of artifact.
- Measure in plane distance
  - Two BBs at the center of module 3.
  - 100 mm


PHYSICS
ACCES#
IMAGES2
M
CONTRAST:
SE:30821
IM:1
Ar: 399.5
Av: 4.9
SD: 3.2
Ar: 397.7
Av: 0.0
SD: 4.2
Ar: 400.5
Av: 4.4
SD: 3.4
Ar: 399.5
Av: 4.5
SD: 3.4
R
10 cm
Ar: 420.1
Av: 3.2
SD: 3.3
DFOV350
TILT:0
0
0mm
National Naval M.C.
W 102 : L 0
P


PHYSICS
ACCES#
IMAGES2
M
CONTRAST:
SE:30820
IM:1
R
99.9 mm
10 cm
P
DFOV350
TILT:0
0
0mm
National Naval M.C.
W 102 : L 0

High Contrast Resolution

- Previously acquired adult abdomen image
  - WW = 100 WL = 1100
  - Values can be adjusted slightly to optimize the visualization of the bar patterns
- Record the highest spatial frequency visualized
  - 4, 5, 6, 7, 8, 9, 10, and 12 lp/cm
  - Adult Abdomen Protocol
    - The 5 lp/cm must be clearly resolved
- Repeat test using the HRC protocol
  - 6 lp/cm must be clearly resolved


PHYSICS
ACCES#
IMAGES2
M
CONTRAST:
SE:31064
IM:5
R
10 cm
DFOV250
TILT:0
0
0mm
National Naval M.C.
W 102 : L 1000
P

CTDI Data

- 3 clinical protocols tested
  - Adult Head
  - Adult Abdomen
  - Pediatric Abdomen
- Axial scans must be used
  - kVp, mA, exposure time, N, and T must remain the same

CTDI Data

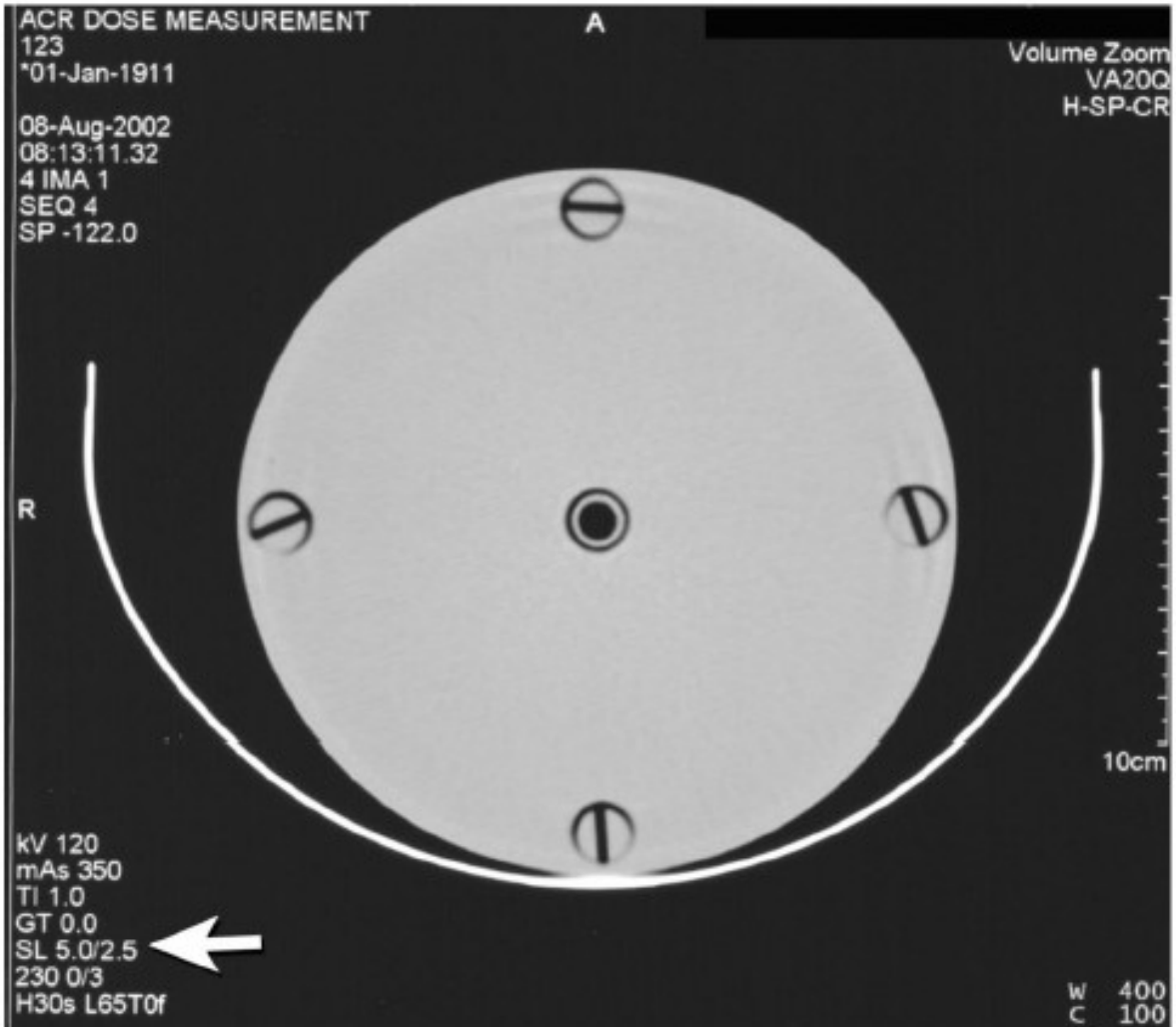
- CTDI Phantoms
  - 16 cm (Head and Peds Abdomen)
  - 32 cm (Adult Abdomen)
- Location
  - ABD protocols on table top
  - Head protocol in head holder
- Images
  - Non chamber holes must be filled
  - Phantom must be centered

CTDI Data

- Measurements
  - Average of 3 center measurements
    - 3 measurements must be within 5%
  - Average of 3 measurements at 12 o’clock position
    - 3 measurements must be within 5%
- CTDI Reference Values
  - Based on AAPM & ICRP Reports
  - No pass or fail criteria on dose

CTDI Phantom Image

Medical Physics, Vol. 31, No. 9, September 2004



McCollough *et al.*: Phantom portion of the ACR CT accreditation program

Dose Calculator Spreadsheet (Exposure)	CTAP ID Number	
Section 9 - Radiation Dosimetry (Adult Head)		
Use the TAB key to move between data entry cells in the column named *Measured*.		
CTDI Head Phantom (16-cm diameter PMMA Phantom)	**Measured**	**Calculated**
kVp	120	
mA	250	
Exposure time per rotation (s)	0.8	
Z axis collimation T (mm)[1]	5	
#data channels *used* (N)[1]	4	
Axial (A): Table Increment (mm) = (I)[1] OR Helical (H):Table Speed (mm/rot) = (I)[1]	20	
Active Chamber length (mm)	100	
Chamber correction factor	1	
Center		
Measurement 1 (mR)	950	
Measurement 2 (mR)	955	
Measurement 3 (mR)	955	
Average of above 3 measurements (mR)		953.3
Head CTDI at isocenter in phantom (mGy)		41.5
12 o'clock position		
Measurement 1 (mR)	954	
Measurement 2 (mR)	954	
Measurement 3 (mR)	952	
Average of above 3 measurements (mR)		953.3
Head CTDI at 12 o'clock position in phantom (mGy)		41.5
CTDIw (mGy)		41.5
Clinical exam dose estimates (using measured CTDIw and site's Adult Head Protocol from Table 1)		
CTDIvol (mGy)	=CTDIw*N*T/I	41.5
DLP (mGy-cm)	=CTDIvol*17.5	725.7
Eff Dose (mSv)	=DLP*0.0023	1.7
[1]See definitions on page 3 of the Phantom Testing Instructions.		
These spreadsheet pages MUST be printed and attached to the back of the Site Scanning Data Form.		
Make sure to include your CTAP ID number in the space above.		
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Reference Values

- CTDIw
  - Head
    - 60 mGy
  - Abdominal
    - 35 mGy
  - Peds Abdominal
    - 25 mGy

Common Operator Errors

TABLE III. Common operator errors.

Scans acquired using parameters that do not match those listed in Table I of the site scanning data form (kVp, mAs, scan width, detector configuration, reconstruction algorithm, scan and reconstruction FOV, etc.)
Incorrect detector configuration (values of N and T) listed in Table I
Incorrect calculation of pitch or table increment
Not submitting a SMPTE pattern or alternate video test pattern
Poor phantom alignment (central wire not centered in ramp, all 4 BBs not the same brightness)
Placing images in the wrong positions (boxes) on the films submitted to the ACR
Filming images with the wrong window width and window level settings
Wrong size or wrong position ROIs
Submitting images having obvious artifacts or other deficient results
Performing CTDI scans using the wrong detector configuration (values of N and T)
Not submitting the printed Excel "dose calculator" spreadsheet
Not noting the difference between mA, mAs, and effective mAs (=mAs/pitch) when completing the forms
Not displaying sufficient technical parameters on the printed films (all scan parameters must be shown)
Positioning ROIs such that the annotation covers important portions of the image
Using too small or too large a reconstruction FOV

References

- Computed Tomography (CT) Accreditation Program Phanotom Testing Criteria

- McCollough, et. al., “The Phantom Portion of the American College of Radiology (ACR) Computed Tomography (CT) accreditation program: Practical Tips, artifact examples, and pitfalls to avoid”, Med. Physics, 31 (9), pp. 2423-2442, September 2004.

- Site Scanning Instructions for Use of the CT Phantom for the ACR Computed Tomography Accreditation Program

Questions?